DOCUMENT RESUME

ED 134 743 CE 009 547

AUTHOR Benson, Robert T.
TITLE Agricultural Electricity. Electric Controls. Student Manual. Report No. 820/20.
INSTITUTION Clemson Univ., S.C. Vocational Education Media Center.
SPONS AGENCY South Carolina State Dept. of Education, Columbia. Vocational Agriculture Section.
PUB DATE 74
NOTE 17p.

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS *Agricultural Education; *Agricultural Engineering; *Electrical Systems; *Electric Circuits; Electronics; Equipment; Instructional Materials; Secondary Education; Vocational Education

ABSTRACT

Addressed to the student, this manual presents terms, abbreviations, and symbols used in discussing manual or automatic control of the flow of electric current. Diagrams accompany discussion of the following types of control devices and principles of operation: Heat sensitive controls (thermostats, thermal relays), light sensitive controls (photo-electric cell), limit switches (applications and types), fractional horsepower motor starters (starting switches), time clocks, electromagnets (solenoid, relays), and switches (toggle, push button). (TA)

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AGRICULTURAL ELECTRICITY

ELECTRIC CONTROLS

Student Manual

Prepared by

State Department of Education
Office of Vocational Education
Vocational Agricultural Section
Columbia, South Carolina 29201

In Cooperation With

Vocational Education Media Center
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1974

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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ACKNOWLEDGEMENTS

Sincere appreciation is expressed to the following organizations and their representatives who assisted in the development of this student manual on electric controls:

Carolina Power and Light Company
Duke Power Company
South Carolina Electric and Gas Company

This publication was prepared and edited by Robert T. Benson, Vocational Materials Specialist, Vocational Education Media Center. Illustrations were prepared by Ronald D. Mattox, Art Director, Vocational Education Media Center.

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INTRODUCTION

Where you have a system using electricity for lights and power, you must have some means of manual or automatic control of the flow of electric current. This control can be anything from a simple toggle switch to a complex system of sensing devices and switches. In many applications in the home and on the farm, more and more control devices are being used.

All automatic control devices are operated by a change in a condition. This condition can be the amount of heat, light, weight, or movement. When this condition is sensed, it can be used to activate a switch or other device to effect the control desired.

Some of the control devices which we will consider in this unit are:

1. Tumbler switches
2. Fractional horsepower motor starters
3. Limit switches
4. Line voltage thermostats
5. Photo-electric cell
6. Magnetic relays
7. Percentage timer
8. Push button stations
9. Time delay relay

We will consider each control device and its principle of operation, but first a few definitions of terms and symbols will help us to better understand the material.

TERMS, ABBREVIATIONS, and SYMBOLS

1. *Anode* – A positive electrode. The plate of an electron tube is the anode.

2. *Bi-metal* – A laminated strip or disk of metal made by welding two sheets of different metals together.

3. *Cathode* – A negative electrode. The filament of an electron tube is a cathode.

4. *Electromagnet* – A core of magnetic material (usually soft iron) surrounded by a coil of wire through which a current is passed to magnetize the core.

5. *Induction* – The production of an electrical current by passing a wire through a magnetic field produced by a permanent or electromagnet.

6. *Magnet* – A device that can attract iron or steel to itself. It may be a permanent magnet or an electromagnet.

7. *Microswitch* – A specially designed switch that will turn on or off with a much smaller force and travel distance than is required to operate a conventional light switch. These switches are often constructed so they can be wired to operate either as a n/o or n/c switch.

8. *Relay* – A device which uses a small change in current in one circuit to produce a large change in current in another circuit. Many relays consist of a switch operated by an electromagnet; however, transistor-like devices can be used.

9. *Magnetic Contactor* – An electrically operated switch designed for heavier electrical loads.

10. *Motor Starter* – A magnetic contactor with motor overload protectors and auxiliary contacts for control circuits.

11. *Non-Grounded Hot Conductor* – That portion of an electrical circuit which operates at the higher voltage. This is the conductor which is fused and switched. This "hot" wire is usually identified as a black or red wire.

12. *Grounded Neutral Conductor* – That portion of an electrical circuit which operates a zero voltage. This conductor should not be fused or switched and is usually identified as a white wire.

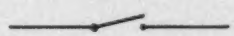
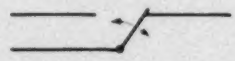
13. *Equipment Ground* – A separate wire (not used as a circuit conductor) which connects the metallic body or frame of a tool or appliance to a suitable ground. This wire is usually smaller than the circuit conductors and may be bare or covered with a green plastic jacket.

14. *Transformer* – A device for increasing or decreasing the voltage or pressure in an electrical circuit.

15. *Thermostat* – An automatic control switch, cutting on or off with temperature changes.

16. *Switch* – A device for turning off or on the flow of current.

Types of Switches

Term	Abbrev.	Definition	Wiring Symbol
Normally Open	N/O	A switch which is open until actuated.	
Normally Closed	N/C	A switch which is closed until actuated.	
Single Pole	SP	Makes and breaks a single contact.	
Double Pole	DP	Makes and breaks 2 contacts simultaneously.	
Three Poles	3P	Makes and breaks 3 contacts simultaneously.	
Single Throw	ST	A simple on and off switch.	
Double Throw	DT	Breaks one contact and makes another one.	

HEAT SENSITIVE CONTROLS

The first principle we shall consider is how heat can be used to trigger a mechanism which will either directly or indirectly open or close a switch. Two of the control devices covered in this unit use heat in their operation. In addition, circuit breakers also operate on the same principle as the bi-metallic strip thermostat.

When the temperature of a solid is changed, a corresponding change results in the dimensions of the solid. As it is heated, the solid will expand and as it is cooled, the solid will contract. However, it has been found that different materials have different coefficients of expansion. (No two metals have the same coefficient of expansion.) Coefficient of expansion is the increase in the unit measurement of a solid when its temperature is raised one degree (Figure 1).

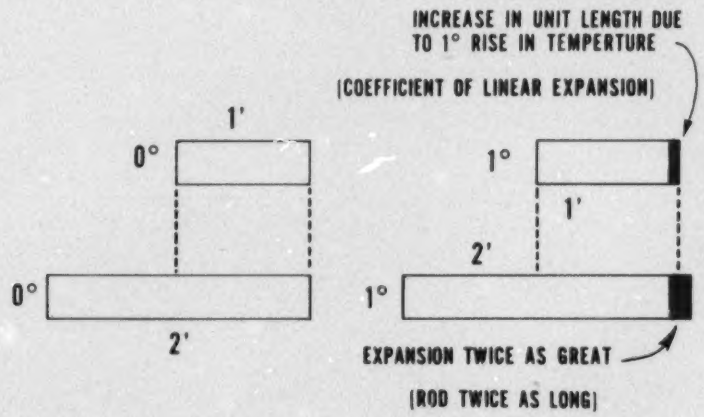


Figure 1. Coefficient of Expansion

In automatic controls, we are primarily interested in the coefficient of linear expansion. If two different metals are securely fastened together and the surrounding temperature is changed, what happens to the metal strip?

Suppose a bi-metallic strip of brass and iron were constructed. Brass has a greater coefficient of expansion than iron. As the temperature rises, the brass expands more than the iron so the strip bends toward the iron. As the temperature drops, the brass contracts more than the iron so the strip bends toward the brass (Figure 2). The bi-metallic strip may be used in coil or in a straight bar as illustrated.

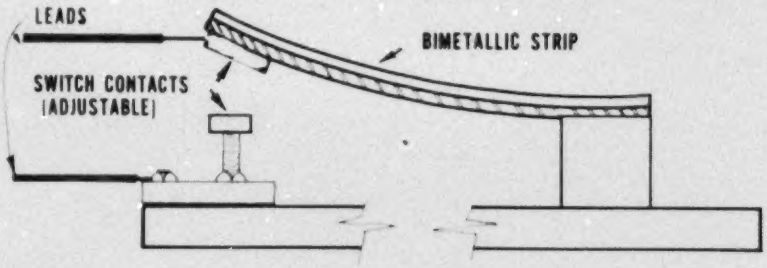


Figure 2. Bi-metallic Thermostat

This principle of unequal expansion is used in thermostats, thermometers, circuit breakers, electric motor overload protection devices and many other applications.

THERMOSTATS

Thermostats probably are one of the most commonly used types of sensing devices. They are found on all types of heating and cooling systems, for example, home heating, water heaters, cooking appliances, ventilation fans, air conditioners, and refrigerators. They are constructed of materials which expand or contract rapidly and readily when heated or cooled. It is the expansion and contraction which is used to operate the switch. There are basically three types of thermostats: bi-metallic, wafer and bellows.

Some thermostats are used to start cooling devices when the temperature goes above a set point. They are called cooling thermostats. **Cooling thermostats close when the temperature increases.** An example of where we would find this type of thermostat would be on a ventilation fan or an air conditioner. Some thermostats are used to start heating devices when the temperature drops below a set point. They are called heating thermostats. **Heating thermostats close when the temperature decreases.** An example of where we would find this type of thermostat is on a heating system. The closing action of these two types of thermostats is obtained in the mechanical linkage between the sensing device and the switch contact points.

1. Bi-metallic Thermostat

This thermostat employs a bi-metallic strip. The switch contact points may be closed directly by the bi-metallic strip (Figure 2). The strip may also be coupled through a mechanical linkage to a snap action switch or to a mercury switch. Adjustment of the temperature setting normally is done by varying the pressure against which the bi-metallic strip must operate.

2. Wafer Thermostat

This type senses temperature change by use of a "wafer" filled with a heat sensitive fluid such as alcohol (Figure 3). These are commonly used on chick brooders. The wafer consists of two thin metal discs which are sealed around the outside edge. The center is free to move and is connected to a switch. When the wafer is warmed by the surrounding air, the alcohol vaporizes causing the wafer to swell or expand. When cooled, the vapor condenses and the wafer contracts.

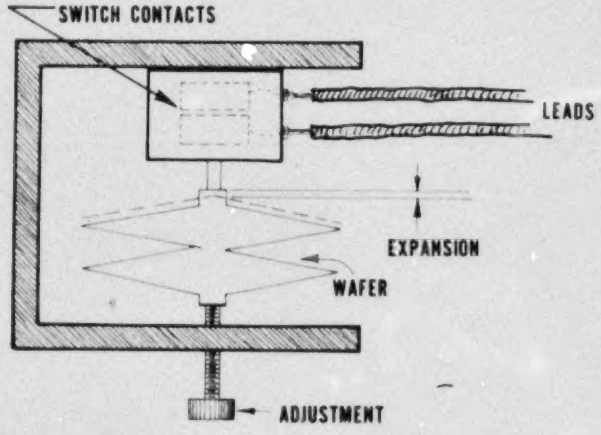


Figure 3. Wafer Thermostat

The motion of the wafer is transferred to a switch. Adjustment within the expansion range of the wafer is made by turning an adjustment screw. This increases or decreases the amount that the wafer must expand before it operates the switch. Different wafers may be used for different temperature ranges. Sometimes two or more wafers are stacked to give greater sensitivity. Dotted lines show the expanded position of the wafers. Wafer thermostats are generally the least expensive of all thermostats.

3. Bellows Thermostat

A bellows is a chamber which can be expanded and contracted. It is much like several wafers set on top of each other, the centers drilled out, and then all outer sections joined together. One end of the bellows is coupled to a switch. The other end is connected through a very small diameter tube to a bulb (Figure 4). In some units, the capillary tube is wrapped in the form of a coiled spring and the bulb is eliminated. The bulb, tube and bellows are filled with a heat sensitive liquid. The action of this thermostat is the same as for the wafer type. As the bulb is heated, the fluid expands the bellows which is rigidly fastened to the thermostat case so that any movement of the bellows is transferred to the pivoting arm and then to the contact points.

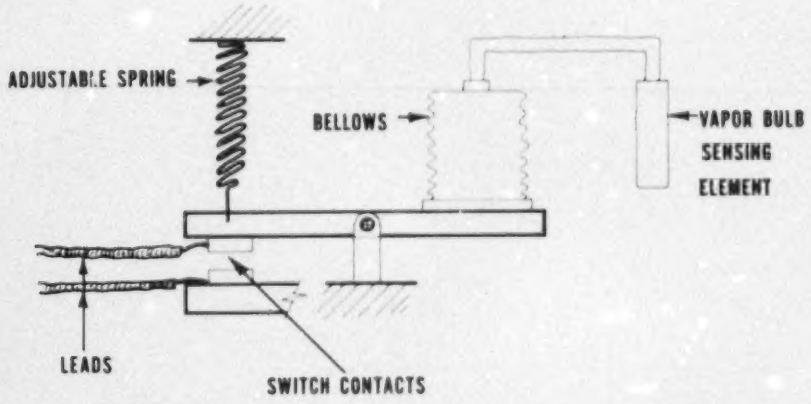


Figure 4. Bellows Thermostat

In Figure 4, as the bellows is heated and expands, the pivot arm is forced down thus opening the contact points; as the bellows is cooled and contracts, the pivot arm is drawn up causing the contact points to close. One advantage of this type of thermostat is that the switch can be located conveniently some distance from the heat source due to the use of the capillary tube between the bulb and the bellows. Temperature range is adjusted by varying the pressure against the linkage to the switch contact points. Bellows thermostats are more expensive than most other types.

The bellows and wafer thermostats work on a thermal principle similar to the thermal expansion of solids. Both gases and liquids have similar properties to metals in that they will expand when heated and contract when cooled. However liquids and gases expand more when heated than do metals, when each are heated the same.

Metals have different coefficients of expansion while all liquids and gases have about the same coefficient of expansion. All gases expand about the same amount. When heated one degree, if the pressure remains constant, their volume will increase about the same amount. However, if their volume remains constant, then there will be an increase in pressure when the gas is heated.

THERMAL RELAYS

The thermal relay provides the same switching function as a magnetic relay, but is much quieter. The thermal relay has a small resistance heater which is energized by the sensing device; the heat bends a bi-metallic strip closing the relay and the circuit is completed. These may be used in series for sequential switching. The first will energize the second heater and so on throughout the sequence (Figure 5).

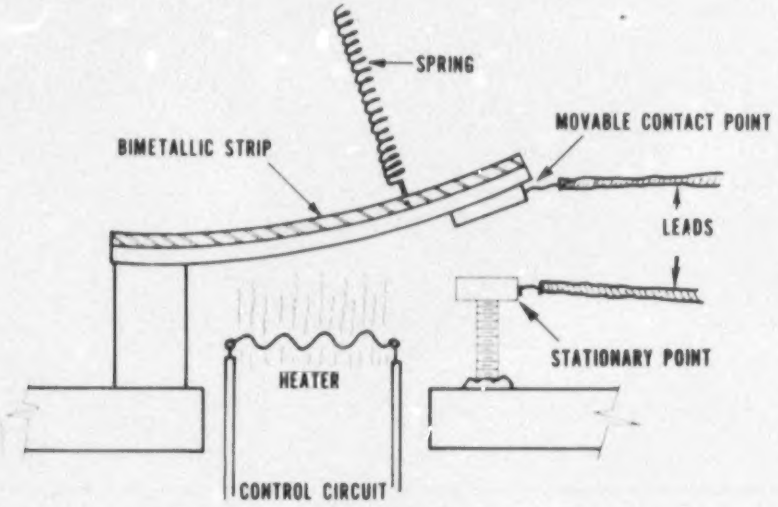


Figure 5. Thermal Relay

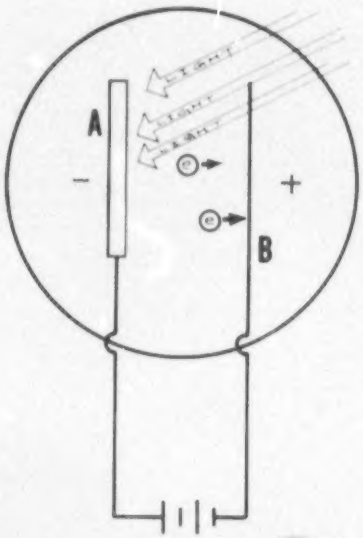
LIGHT SENSITIVE CONTROLS

The next control device we will consider is the photo-electric cell. Photo-electric cells (Figure 6) are constructed of materials that are sensitive to light. They are commonly used to turn on outside lighting fixtures for general illumination. The photo-electric cell senses light or the lack of it. It will turn the light on when outdoor lighting falls below a preset level. The light will remain on until daylight becomes bright enough to activate the cell to turn the light off. Moonlight is not bright enough to affect the photo cell. Photo cells must be mounted so that light from the controlled fixture does not shine on the sensing device and so that other light sources such as automobile headlights will not strike it and cause it to function.

What is a photo-electric cell and how does it work? A photo-electric cell is a vacuum tube similar to a radio tube with a wire in the center that serves as an anode, the positive pole (+), and a metal plate with a thin chemical coating of a light sensitive metal such as sodium, potassium or cesium, which serves as the cathode, the negative pole (-).

When light strikes the plate (cathode), the light sensitive metal releases free electrons which in the vacuum tube travels or are drawn toward the wire (anode). This flow of electrons from the plate to the wire constitutes an electrical current flowing in the circuit (Figure 6). The current produced in the photo-electric cell is proportional to the intensity of the light striking the plate. As more light strikes the plate, more electrons are freed and the current produced is greater. As less light strikes the plate, fewer electrons are freed; thus the current produced is less. The current produced is very weak; however, it can be measured.

For use as an automatic control, it is determined at what light intensity we wish to have the photo-electric cell control the device, e.g., a light fixture. The current produced at this now determined light intensity is found and the switching mechanism is then set to operate when this level of current is reached.



LIGHT STRIKING CHEMICALLY TREATED SURFACE (A) EJECTS ELECTRONS (E) WHICH ARE DRAWN TO WIRE (B) CREATING A CURRENT.

Figure 6. Photo-electric Cell

LIMIT SWITCHES

A limit switch is operated mechanically by the movement of some object, e.g., a float, a thickness of material, a knot in a rope, or a flap in an air stream. These switches may either start or stop an operation. The switches may return to their original position by the action of a spring, or they may be of a type which require manual resetting.

APPLICATIONS OF LIMIT SWITCHES

Part Operating the Switch	Operation Being Controlled
Float in a water tank	Pumping water into a tank
Thickness of material	Metering grain into an auger or hammer mill
Knot in a rope	Hoisting an object
Flap in an air stream	Moving materials by means of air

The water tank float operates on the principle of buoyant force. Any object will float if the upward force of the water is greater than the weight of the object itself. This is based upon the principle which states: "The buoyant force which a fluid exerts upon a submerged body is equal to the weight of the fluid the body displaces." Therefore, if a body when submerged, displaces a weight of fluid greater than its own weight, the body will float. Therefore, a floating body displaces its own weight of liquid. Applications of this principle are the float in a cattle tank, float in a carburetor and the shut-off in a toilet tank.

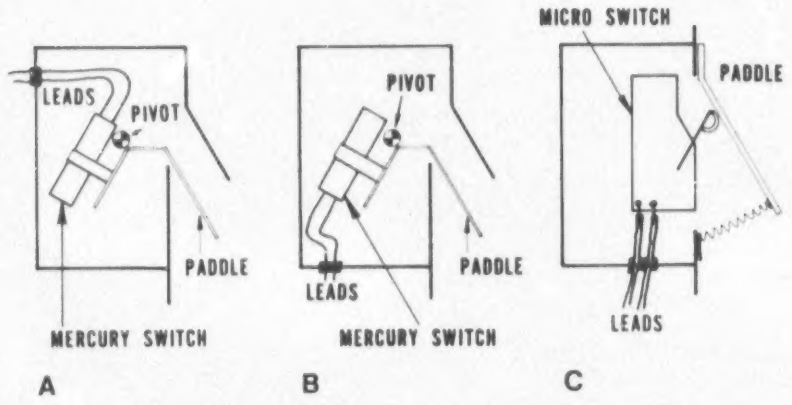


Figure 7. Bin Level Switches

Another type of limit switch is the pressure switch (Figure 7) or bin level switch which can be used as the primary control or safety device in an automatic feeding system. Operation of this switch is simple – the pressure or non-pressure of material on the pressure plate or paddle of the switch can start the feed preparation and conveying system when the feeder or bin is empty and stop the system when the feeder or bin is full.

Two types of bin level switches are illustrated in Figure 7. The mecury switch (7a) – as a material tilts the paddle downward, the mercury switch is tilted upward until the circuit is completed. Whether the circuit is to be opened or closed dictates the posit.on in which the mercury switch is mounted. The diagram indicates that the circuit will close as the paddle is pressed downward. By mounting the mercury switch with the contact points on the lower end (7b), the circuit would be opened when the paddle is pressed downward.

A microswitch (7c) – as the material moves the paddle downward, the paddle will actuate the switch either opening or closing the circuit depending upon how the switch is connected in the circuit.

FRACTIONAL HORSEPOWER MOTOR STARTERS

Starting switches also use the thermal principle such as the built-in heater coil shown in Figure 8.

This device uses a heater coil of known capacity matched to the motor capacity. If the current passing through the coil reaches a point under overload conditions which exceeds the limit of the coil, the heat generated burns the coil apart disconnecting the circuit and protecting the motor. Other similar switches are also available, very often they operate similar to the circuit breaker with a bi-metallic strip. Usually the heater elements are replaceable so that they can be sized to the motor being used.

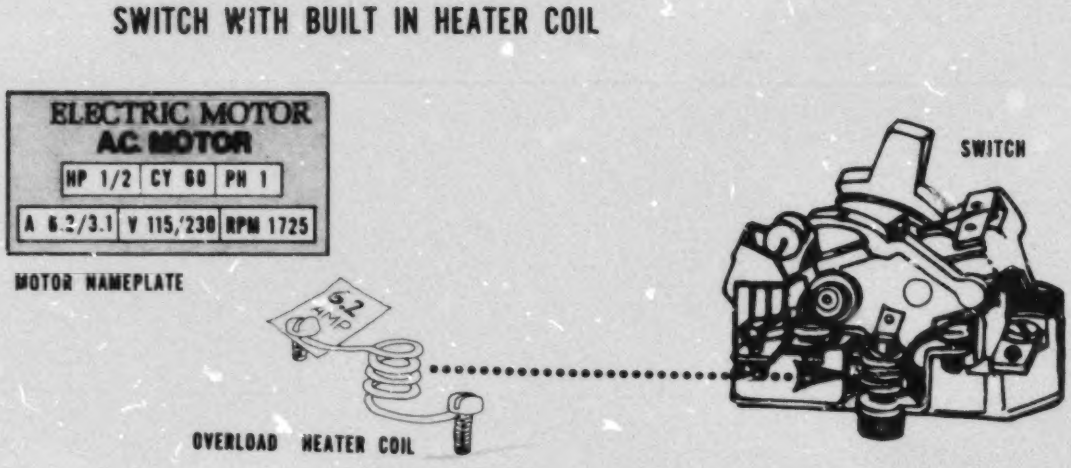


Figure 8. Heater Coil

TIME CLOCKS

The time clock is an electric clock connected to a switch. Time clocks turn equipment on and off at a pre-set time. They are usually operated by a small electric motor (Figure 9).

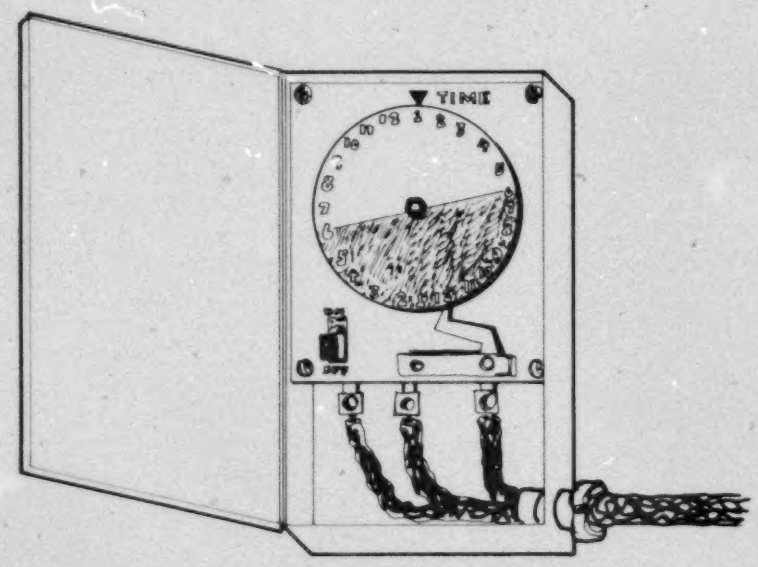


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Figure 9. Time Clock

The drive mechanism turns a large flat disc. On the disc are time markings and adjustable trip pins or bars. As the trip pins or bars rotate with the disc, they turn against the rider which operates the switch controlling the equipment by turning it off or on. The disc may rotate at almost any speed, but one revolution per day is most common. This would be called a 24-hour time clock. The disc would be marked for 24 hours, twelve for day and twelve for night with minute markings within each hour. The trip pins or bars can be set at any point on the disc to give the desired cycle of operation. The clock motor runs continuously and must be connected to the power source ahead of the switch which controls the device to be controlled. To calibrate (set) the time clock, the disc must be turned by hand until the time marking corresponding to the "actual time of day" is in line with a reference point located some place on the time clock mechanism. Follow the directions which are furnished with the clock.

Timers have many uses in agriculture. They can be used to actuate feeding operations, lights, irrigation equipment, silo unloaders, and barn cleaners.

ELECTROMAGNETS

An electromagnet is a single conductor wound around a common core (Figure 10). When current is passed through this simple coil, the current is traveling in the same direction through each loop of the coil and the magnetic lines of force are traveling in the same direction around the wire. When current is traveling in the same direction through several conductors, the lines of force around each conductor join and surround the several conductors. The lines of force join and travel around all of the loops of the coil entering the coil at one end, leaving at the other end and returning outside the coil. Since all lines of force travel down the inside of the coil, the area within the coil becomes a strong magnetic field. We also see that one end of the coil has become a North Pole and the other a South Pole similar to a permanent magnet.

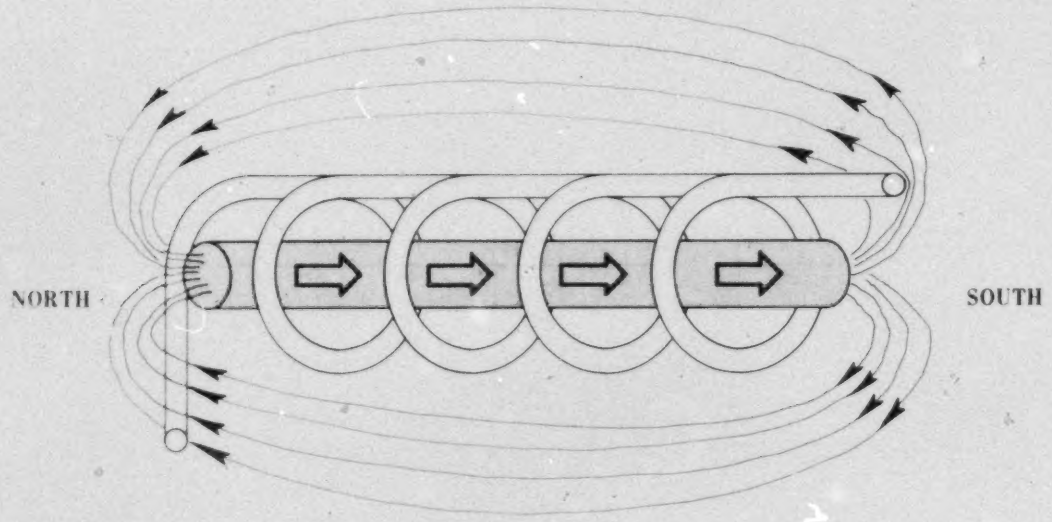

Figure 10. Electromagnet

Air is a poor conductor for lines of force so that the coil loses many of the lines of force around it to the surrounding air. In order to strengthen the field within the coil, it is necessary to place a soft iron core within the coil replacing the air. This soft iron core is easily magnetized and will make a much stronger magnetic field. This then becomes a true electromagnet. With a given amount of current passing through a coil, the strength of the electromagnet produced is directly proportional to the number of turns in the coil. The strength of the electromagnet having a given number of turns is also directly proportional to the amount of current passing through the coil. By varying the number of turns in the coil and the amount of current passing through it, virtually any strength of electromagnet may be obtained.

SOLENOID

By definition, the solenoid is a tubular coil with an iron core capable of producing a magnetic field. It is primarily used as an electromagnet with the iron core being free to move (Figure 11). This freedom of movement allows the core to be free to do mechanical work such as shutting off switches or engaging gears as in a dishwasher or automobile starter. To reverse the movement, the current is allowed to enter the coil from the opposite direction. This in turn reverses the direction of the lines of force and the movement of the core.

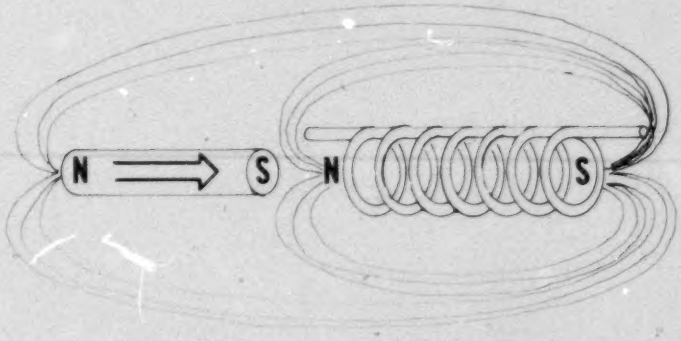

Figure 11. Solenoid

Considerable use is made of electromagnetism in automatic controls. Some of the more common types of controls are magnetic relays, voltage regulators and solenoid valves.

RELAYS

Relays are used in automatic control systems to switch electrical loads which are beyond the current carrying capacity of the sensing device. For example, a relay could be used with a light duty thermostat to control a piece of heavy duty heating equipment.

Two types of relays are commonly used – magnetic relays and thermal relays.

1. Thermal Relays

Thermal relays were discussed earlier in the unit. (See Figure 5.)

2. Magnetic Relays

The most important part of this relay is the electromagnet which responds to the signal from a sensing device (Figure 12). The switching contacts are placed on a movable steel or iron plate within the magnetic field of the electromagnet. When current from the sensing device flows through the coil, the magnetic field attracts the movable plate and closes the contact point which completes the circuit to the load. When the sensing device calls for a stop, the current ceases to flow through the coil, the magnetic coil is no longer energized, so the contact points are opened by spring tension. These controls are noisy and for some applications are not practical.

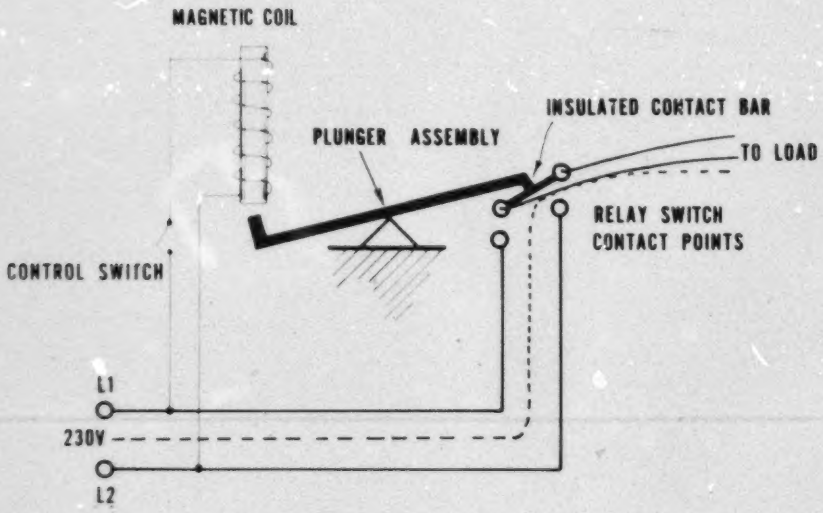

Figure 12. Magnetic Relay

SWITCHES

Switches are used in all control circuits whether they are manually or automatically controlled circuits. In this unit and the practical exercises, two types of switches will be used. These are the common toggle switch which is usually a single pole, single throw type; and the commonly used push button station.

The single pole, single throw toggle switch can be illustrated by the knife switch illustrated in Figure 13. Here, when the knife blade is lifted, the contact is broken and the circuit is opened. When the blade is pressed down, contact is made and the circuit is complete. In the switches we commonly see and use, springs are used to help make and break the contacts to minimize arcing. In mercury toggle switches, the tipping of the mercury tube makes or breaks the circuit.

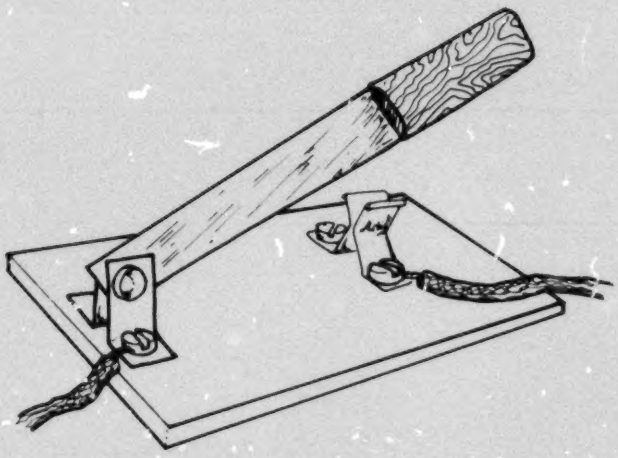

Figure 13. Knife Switch

Push button switches are commonly used in circuits where motors are controlled, they are used in conjunction with magnetic relays. The push button switch is actually a normally open and normally closed switch. In Figure 14 are three drawings showing the three positions of the switches in normal use.

When the start button is pressed, it will complete the circuit through the relay and the stop button which is a normally closed switch, the motor will then operate until the stop button is pressed which opens the circuit. In order for the motor to be restarted, the start button must be pressed.

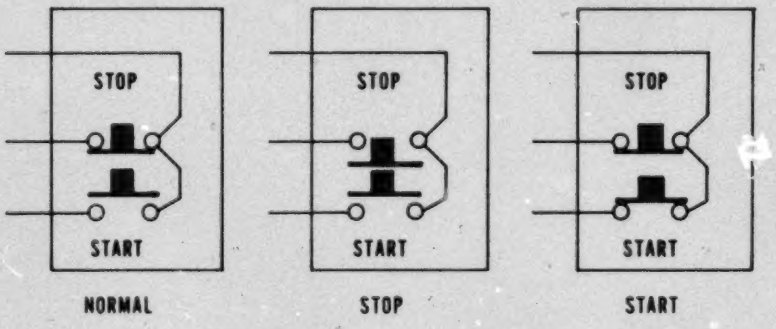

Figure 14. Push Button Switches